CFD Simulation of Various Types of Solid Particles in Oil Pipe Flow to Evaluate the Pressure Losses

By

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14963

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical)

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CERTIFICATION OF APPROVAL

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Mechanical Engineering Programme
Universiti Teknologi PETRONAS
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Approved by,

____
(AP Dr. Hussain H. Al Kayiem)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken o done by unspecified sources or persons.

Tang Mei Huong

ABSTRACT

In the process of liquids transportation, mainly the oil products, one of the most important elements is the pipelines flow assurance through maintaining lowest pressure losses. This study presents investigation results on the effect of the solid in liquid horizontal pipe flow. The influence of the particle's diameter (0.25mm, 0.50mm, 1.00mm) and concentrations (10%, 15%, 20%) on the pressure loss of pipelines at various flow rates was simulated and studied computationally using the ANSYS-CFX software. The mesh independency study has been achieved so that the results produced will not be affected by the number of mesh. Three cases of each fluid were simulated, as single phase flow, as homogenous solid in liquid flow, and as two layer flow. The simulated liquids, oil and water, were considered as Newtonian fluids, and the flow was fully developed region, at constant temperature.

Results demonstrated that the higher the fluid velocity, the pressure loss along the pipelines will be higher in both homogeneous and two layer two phase flow. In homogeneous flow, sand concentration of 10% with velocity of 0.5m/s and sand size of 0.25mm will have pressure drop of 389.75 Pa while sand concentration of 20% with same velocity and sand size will have pressure drop of 515.75 Pa. However, in the case of 0.25mm and 1.00mm sand size with velocity of 0.5m/s and sand concentration of 15%, there is no significant changes on the pressure drop which is 451.50 Pa and 451.25 Pa. This indicates there is no effect of solid particle's diameter on the pressure drop of the flow. In homogeneous two phase flow, the fluid velocity has more effects on the pressure drop.

For the two layer two phase flow, the increase of solid particle concentration will cause the increase of pressure drop. With sand concentration of 10%, 0.5m/s of fluid velocity and 0.25mm of sand size, the pressure drop is 1448 Pa. The pressure drop further increases to 1940 Pa when the sand concentration is 20% while other parameters remain the same. It is realized that the concentration of solid particles will have more effects on the pressure drop compared to the fluid velocity in two layer two phase flow.

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CHAPTER 1:
INTRODUCTION

1.1 Background of Study

Oil and gas industry has grown rapidly over the years in Malaysia. According to Abdullah (2012), this industry is very important to the economy of Malaysia as it contributes approximately 20% of the national Gross Domestic Product (GDP). It was also predicted that the oil and gas industry will generate a Gross National Income of RM131.4 Billion by 2020. Therefore, it can be seen that oil and gas industry plays an important role in the growth and development of a country's economy.

In the process of oil production, one of the most important elements is the pipelines. Pipelines are used to transport oil, natural gas, slurry and others. During the process of transportation, the sand which is contained in the slurry may deposit on the bottom of the horizontal pipelines. As time passes, it will form a layer of stationary sand deposit which is the sand bed. The existence of sand bed will bring effects on the rate of production as it will cause a pressure drop in the pipelines. Hence, this subject must be concerned and included during the pipelines design stage.

This study will investigate the effect of the solid particle's diameter and concentration on the pressure loss of pipelines as well as the effects of fluid velocities on it. The diameter and concentration of solid particles and fluid velocities are among the factors that will cause changes on the pressure loss. This study is vital as it will determine the most suitable pump to be used which is one of the major operation cost. To conduct this study, computational fluid dynamics

(CFD) simulation is carried out by using the ANSYS-CFX software. In the simulation, few assumptions have been made such as the oil and water are considered as Newtonian fluid and are in fully developed region. However, the variation in temperature is not considered in the simulation.

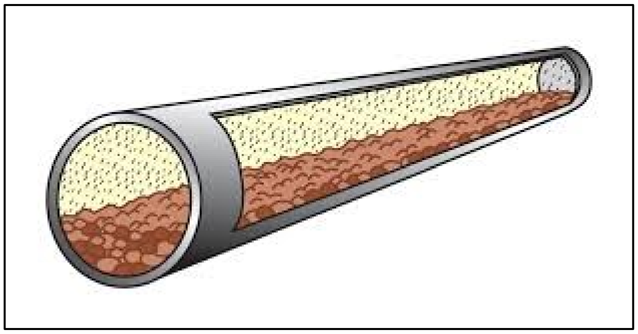

Figure 1: Dense Phase-Bed Flow. (Mactenn, 2014)

1.2 Problem Statement

Pressure drop in pipelines is a challenge to engineers in oil and gas sector. The pressure loss will cause the operating company to use powerful pumps to pump the slurry across the pipelines and thus, affecting both the capital expenditure and the operating expenditure. Therefore, this study is important to determine the effect of the diameter and concentration of solid particles and fluid velocity on the pressure loss. When the pressure loss is predicted, the needed pumping power will be determined and therefore, will be able to transport the slurry to the destination. This method will reduce the time consumed for transportation and also reduce the operating cost.

1.3 Objectives

The objectives of this project are:

i. To investigate the influence of the solid-in-liquid two layer flow on the pressure drop in pipe flow.

ii. To model and simulate two layer two phase flow by CFD to predict the pressure drop at various particle size and concentration.

1.4 Scope of Study

This study focuses on the CFD simulations of various solid particles especially in terms of the size (diameter) of the solid particles and its concentration in the pipe flow. By conducting the simulation, the pressure loss in the pipeline can be obtained and the best parameters for a perfect flow can be predicted. Therefore, this study is important to oil and gas industry as it can predict the parameters needed to create a perfect flow which indirectly will reduce the complications in the transportation of oil.

The ranges of parameters used in this study are showed in Table 1.

Table 1: Range of Different Parameters

		Water	Oil (Diesel 2D)
Flow Parameters	Assumptions	• Newtonian • Incompressible • Steady State • Fully Developed	• Newtonian • Incompressible • Steady State • Fully Developed
	Pipe Length, m	20	20
	Velocity, m/s	0.3 0.4 0.5 0.6 0.7 0.8	0.5 (8538 bbl/d) 1.0 (17,075 bbl/d) 1.5 (25,607bbl/d) 2.0 (34,145 bbl/d)
Solid Particle Parameters	Size (Diameter), mm	-	0.25 0.50 1.00
	Concentration, %	-	10 15 20

CHAPTER 2:
LITERATURE REVIEW

The presence of sand in oil is unavoidable and has brought serious problems in pipe flow. It can affect the smoothness of the oil flow and also possess risks in damaging the pipelines. Therefore, the transport of sand through oil pipe is one of the main concerns in oil and gas industry. According to Kaushal and Tomita (2002), slurry pipelines' design parameters include solid concentration profiles, pressure drop and deposition velocity. Faitli (2001) mentioned that pressure loss is one of the main parameters in pipeline designing as it will determine the most suitable pump to be used to transport the oil and this is one of the most expensive parts in the operational cost.

However, there are also few factors that will affect the pressure loss and among them are the size (diameter) of the solid particles and also its concentration. These two parameters affect the pressure loss in pipe as they will cause friction loss. According to Matousek (2002), friction is divided into two types which are the mechanical friction and also viscous friction. The mechanical friction is created through the contact between the solid particles and the pipe wall and it can be permanent or random. On the contrary, the viscous friction is created due to the formation of solid particles in the near wall layer of carrying liquid. In this case, the properties of the carrying liquid near the wall layer are changed.

Friction loss depends highly on the flow conditions and also the pattern of the flow. Matousek (2002) categorized the flow pattern into four: fully stratified flow, fully suspended flow, non-stratified flow and partially-stratified flow. In fully suspended flow, the solid particles are uniformly distributed across the pipe and no solid will deposit or act against the pipe wall. As for non-stratified flow, a small concentration gradient will appear across the pipeline but no contact bed is present. In this case, the particle size and also the solid concentration will not have obvious effect on the solid effect.

Moreover, El-Nahhas et al. (2009) divided slurry into two main types which are the settling and non-settling. The settling slurry will have a range of flow patterns and these flow patterns are relying on the physical properties of the carrier fluid and also the transported solids, the velocity and the concentration of slurry. When reaching one point, the solid particle will form a gravity bed is which called sliding bed or stationary bed. This kind of flow pattern is commonly known as partially-stratified flow and it may be assumed as a pseudo-homogeneous flow. In addition, there are two conditions which are in between of settling flow and also partially-stratified flow: saltation and heterogeneous flow regimes.

In addition, El-Nahhas et al. (2009) also commented that non-settling slurries is a homogeneous flow pattern where the solid particles will settle very slowly and will distribute equally throughout the pipe. It was indicated that the increase in solid particle content will cause the mixture to be no longer regarded as two separate components. The resulting fluid might possess non-Newtonian characteristics which signify an even more complicated situation. In this situation, the solid particle concentration is higher in the bottom of the pipe which also indicates a settling pattern. This settling pattern will cause higher frictional losses compared to homogeneous slurries.

Kaushal et al. (2005) mentioned that most of the previous studies on slurry pipeline systems are depending on moderate solid concentrations such as 26%. In their study, the increase in solid particle concentration will cause the pressure drop to increase in any flow velocity. On the other hand, their study also showed that smaller solid particle size will have less pressure drop than bigger size particle. Kaushal et al. (2005) mentioned that the smaller particle size will have lower pressure drop at lower velocities and has higher pressure drop at higher velocities compared to bigger sized particle. They also explained that the increase in pressure drop for bigger particle size at low velocity is because of the increase in particle amount moving in the bed which is due to gravity.

Furthermore, Kaushal et al. (2005) described that the smaller sized particle will have more pressure drop in higher velocities as the greater surface area will cause more frictional losses in suspension. Furthermore, Nabil et al. (2013) claimed that the bigger sized particle needs more power to compensate the energy loss and the difference between the pressure drops of various particle sizes decreases as the slurry velocities increases.

SUMMARY

The reduction of pressure loss in pipelines will decrease the operational cost of a company and there are many factors affecting the pressure loss which include the velocities of fluid, the concentration of sand particles and the size of the sand particles. Increase in sand concentration will cause higher pressure drop and smaller sand particle size will have lower pressure drop. When the velocity of fluid decreases, the pressure drop will decrease too. The effects of fluid velocities are higher compared to the size of sand particles.

CHAPTER 3:
METHODOLOGY

3.1 Project Work

This project involves Computational Fluid Dynamics (CFD) simulations, the ANSYS-CFX is used. ANSYS-CFX will be used to model the pipelines and later used for simulation to get the pressure loss of the pipelines. In this project, different values for diameters and concentrations of solid particles will be used. In this study, few assumptions were made such as:

- The flow is in horizontal pipe and fully developed.
- The fluid in the pipe is assumed as Newtonian fluid.
- The flow is incompressible and at steady state.
- There is no slip between the two layers (fluid layer & dead bed).
- It is a two layer approach where the upper layer is the homogeneous suspended layer and the lower layer is the dead bed layer.

3.2 Tools required

The tool that is needed in this study is the ANSYS-CFX software. According to ANSYS (2014), this software consisted of various advanced models and technology of a leading CFD software package and it is a high-performance, general purpose fluid dynamics programme that has been implemented to solve different fluid flow problems. This software can provide reliable and accurate solutions quickly and steadily.

3.3 Project Flow

Figure 2: Project Flow of FYP 1

3.4 Project Timeline

Table 2: Gantt Chart & Key Milestones for FYP 1

		WEEK													
NO	**ACTIVITIES**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Selection of Project Topic	**X**													
2	Understanding Project Topic and Information gathering				**X**										
3	ANSYS-CFX Software Practice							**X**							
4	Modelling of the pipe flow											**X**			
5	Simulation of the pipe flow / single phase flow and validation via analytical solution														**X**
6	Simulation of the pipe flow / homogenous two phase flow														

Table 3: Gantt Chart & Key Milestones for FYP 2

		WEEK													
NO	**ACTIVITIES**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Simulation of the pipe flow / homogenous two phase flow and validation via analytical solution (Continue)		**X**												
2	Simulation of the pipe flow / two layers, two phase flow with various particle diameters and validation							**X**							
3	Analysis and presentation of results									**X**					
4	Preparation of technical report for technical paper publication											**X**			
5	Submission of final Report														
6	Viva														**X**

X Key Milestones

CHAPTER 4:
RESULT & DISCUSSION

In this study, three parameters are studied which are the diameter of solid particles, concentration of solid particles and also the fluid velocity. The settings made in the simulations are showed in Table 4.

Table 4: Settings on Pipe Flow

Pipe Length	20m
Pipe Diameter	0.2m
Pipe Material	Galvanised Iron
Density of Water	998.2 kg/m^3
Viscosity of Water	1.002 x 10^{-3} kg/m.s

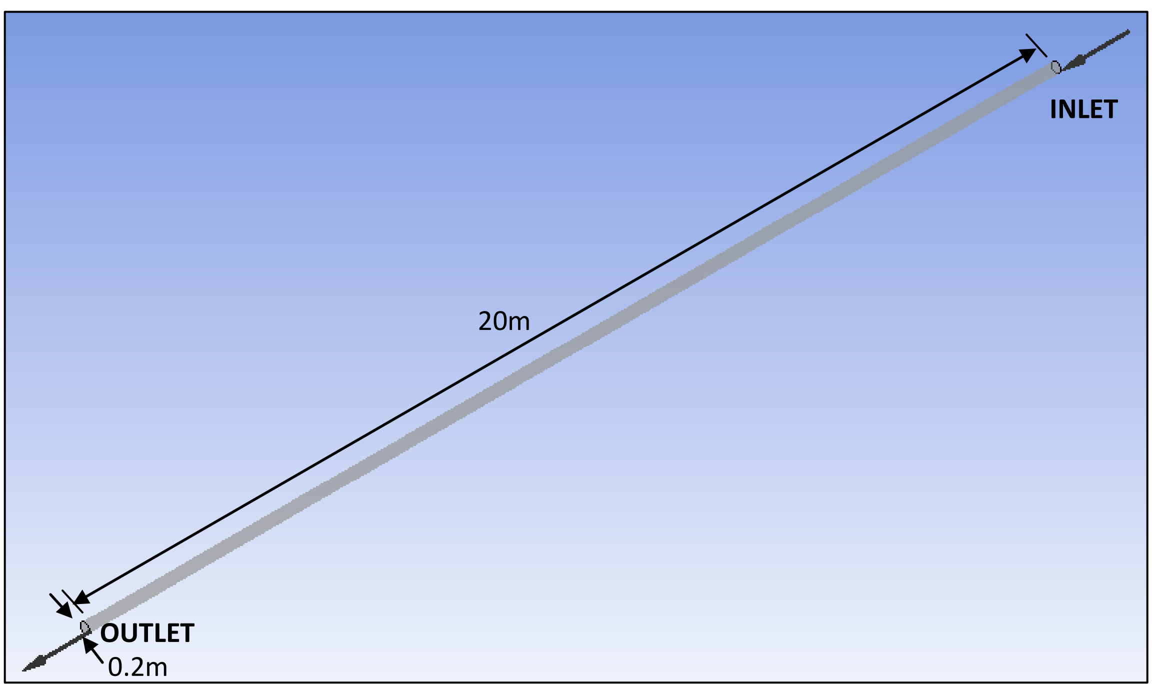

Figure 3: Model of the Pipe

4.1 Mesh Independency Test

Before starting any simulations, the mesh independency test must obtained first as it will affects the accuracy of the final results. According to LEAP CFD (2012), the accuracy of the mesh and boundary conditions depends on the accuracy of the converged solution.

Convergence is important as:

- Residual RMS Error values are reduced to its minimum which is normally 10^{-4} or 10^{-5}.
- A steady state simulation or steady solution has been achieved.

Therefore, mesh independency test implicated that the solution is independent of the mesh resolution. Any increase in the number of elements will not affect much on the results and will remain constant. In this mesh independency test, few settings have been made as follow:

The flow geometry is drawn with pipe length of 10m and diameter of 0.2m. The pipe has three boundaries which are inlet, outlet and wall.

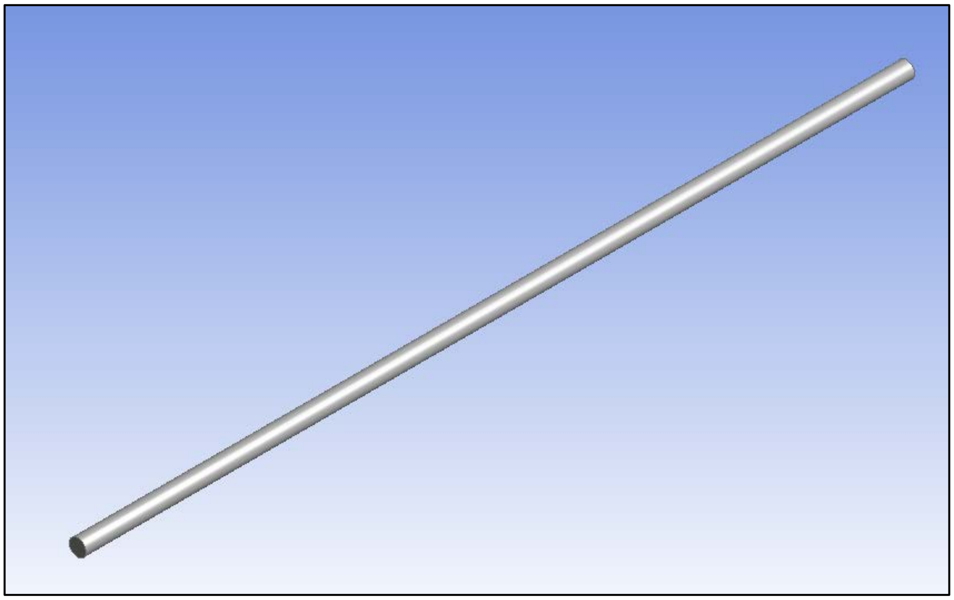

Figure 4: Geometry of the Pipe

For meshing, there are different meshing setup been done for different cases. In this study, six simulations been conducted and the six setups and obtained outcome are shown in Table 5.

Table 5: Setup on Meshing

Meshing	**Mesh 01 (Default)**	**Mesh 02**	**Mesh 03**	**Mesh 04**	**Mesh 05**	**Mesh 06**
No. of Division (Edge Sizing)	Default	80	100	100	110	120
Element Size (Face Sizing)	Default	3.0×10^{-2}	2.5×10^{-2}	2.0×10^{-2}	2.0×10^{-2}	2.0×10^{-2}
Curvature Normal Angle (°)	Default	6	6	6	6	6
Nodes	19840	310545	416639	520539	571641	706410
Elements	16588	295924	396400	495500	543500	676500
Element Quality	0.897	0.180	0.220	0.315	0.292	0.248
Aspect Ratio	1.611	5.942	5.443	4.360	4.448	4.963
Jacobian Ratio	1.540	1.207	1.236	1.239	1.217	1.195
Skewness	0.205	0.121	0.133	0.133	0.139	0.120

Overall, the meshing quality is good and the meshing is shown in Figure 5 and Figure 6.

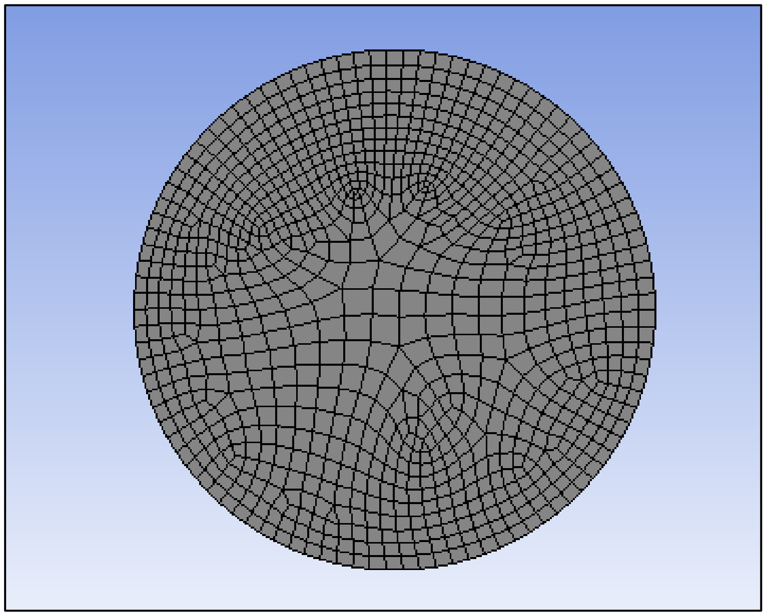

Figure 5: The meshing of the pipe (front)

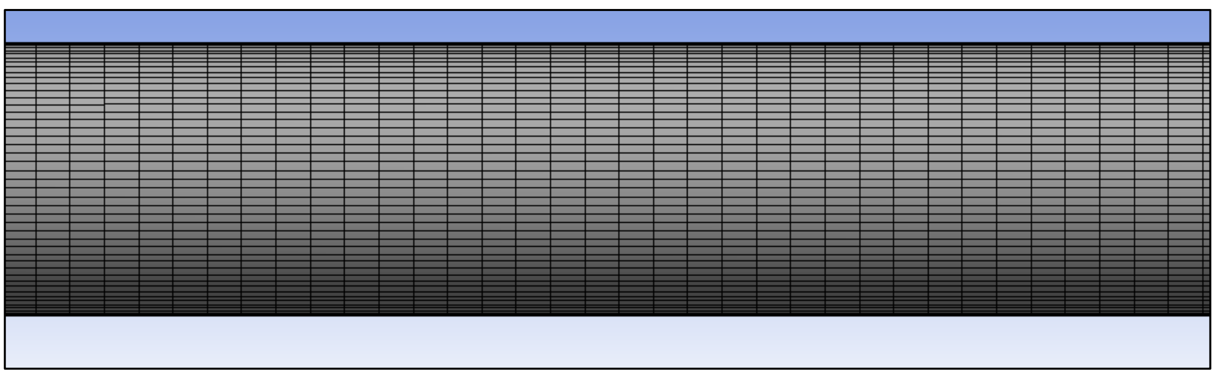

Figure 6: The meshing of the pipe (side)

In the setup, the material set is water and the reference pressure defined is 1 atm. Besides that, there is a gravity defined at y-direction which is -9.81 kg/ms^{-2} and the buoyancy reference temperature is 25℃. At the inlet, it is defined as isothermal with temperature of 25℃ and with turbulent speed which is 0.05 m/s

(Re = 1.1 x 10^4). On the other hand, the outlet has an average static pressure of 0 Pa and the wall is a no slip and rough wall with sand grain roughness of 0.15mm.

From the simulation, the converging trend is shown in Figure 7.

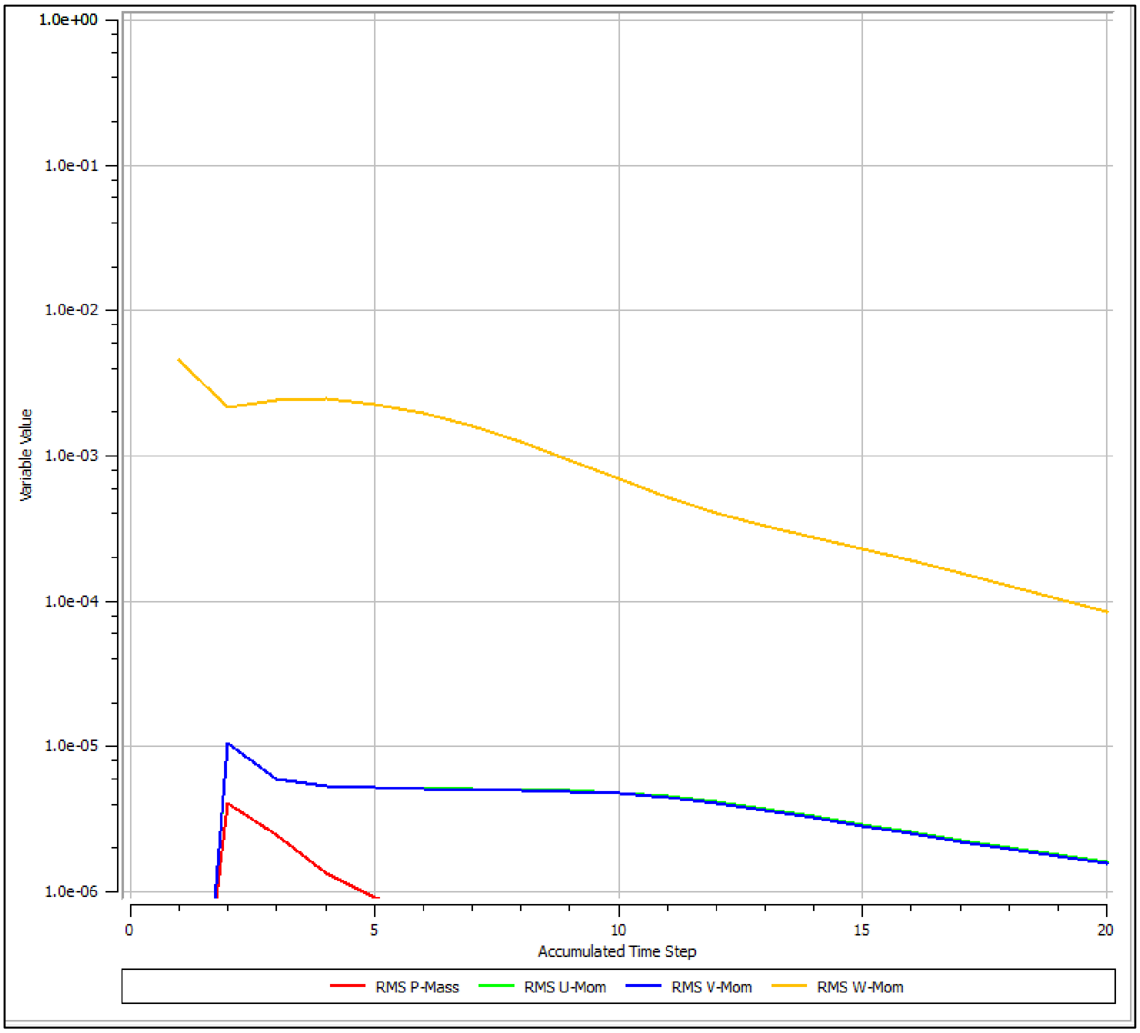

Figure 7: Convergence of the simulation parameters.

From the results, the contour of pipe pressure is obtained and showed in Figure 8.

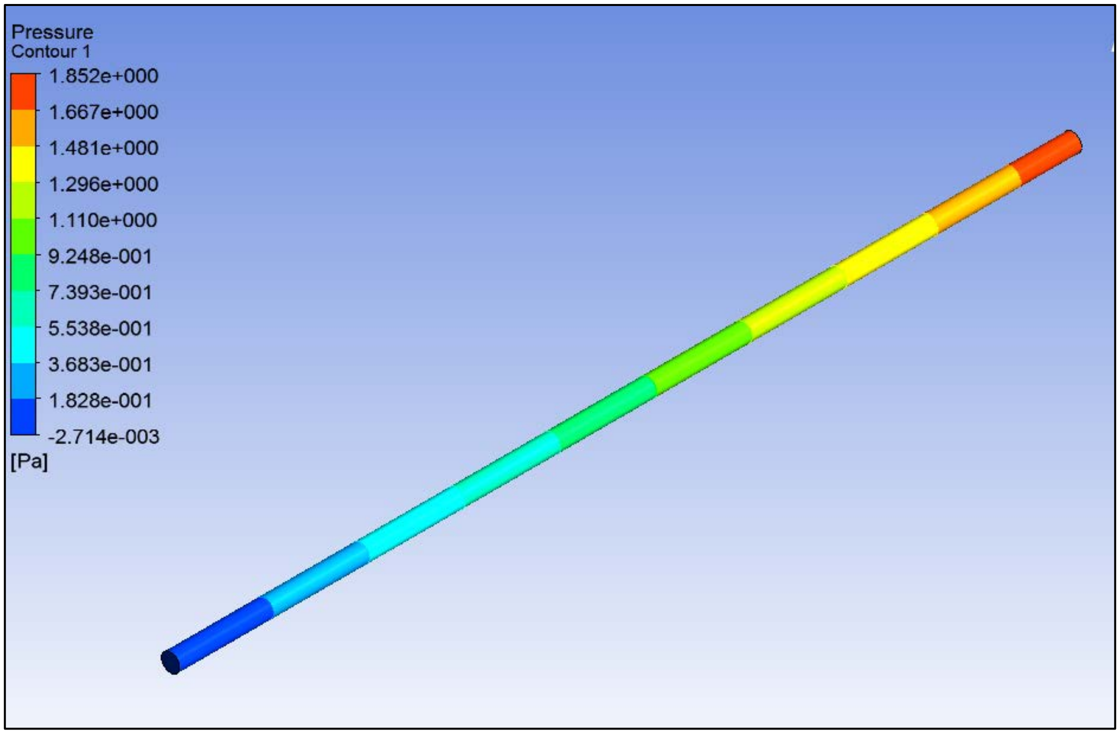

Figure 8: Contour of Pressure

In addition, the pressure of the flows are obtained and plotted in graph. The results obtained can be exported in excel format where the pressure drop can be calculated. The results obtained are tabulated and showed in Table 6.

Table 6: The pressure obtained from six simulations

Number of Element	**Pressure Drop Over Length (Pa/m)**
16588 (default)	0.197
295924	0.188
396400	0.185
495500	0.185
543500	0.183
706410	0.183

From Figure 9, it can be seen that the mesh independency study is achieved at element number of 396400. The mesh independency test is important as it represents the consistency of results even if the number of element increased. Therefore, element number of 39640000 is chosen for the rest of the simulations to avoid and reduce errors.

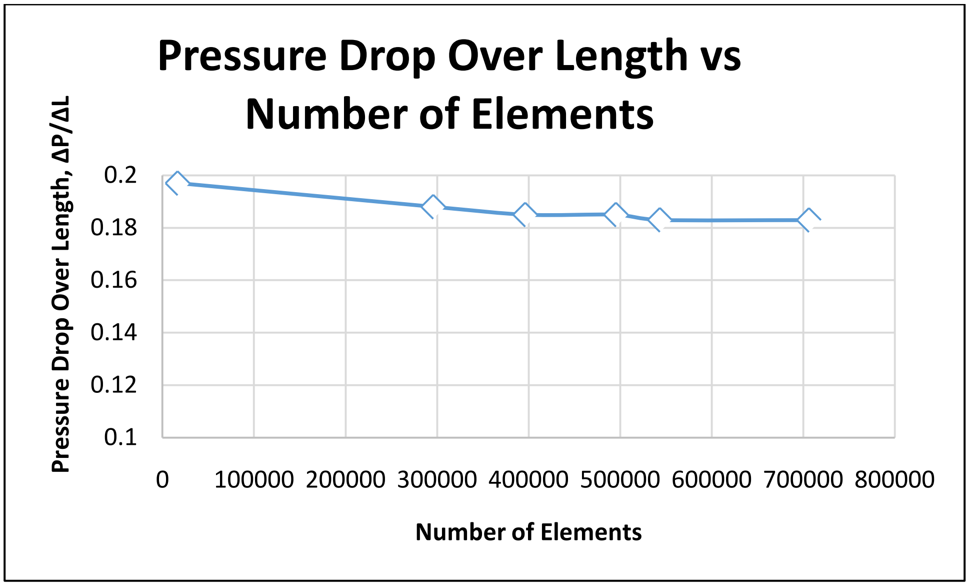

Figure 9: Graph of Pressure Drop vs Number of Element.

4.2 Verification and Validation

4.2.1 Water Verification

<u>Theoretical Calculation</u>

Water Temperature, T = 25°C

Density of Water, $\rho = 997$ kg/m^3

Velocity of Water, V = 0.3 m/s

Diameter of Pipe, D = 0.2m

Dynamic Viscosity of Water, $\mu = 9 \times 10^{-4}$ Ns/m^2

Reynolds Number, Re = $\frac{\rho V D}{\mu} = \frac{997 \times 0.3 \times 0.2}{9 \times 10^{-4}} = 66463.33$ (turbulent)

Sand Grain Roughness, ε = 0.15mm

Using Colebrook Equation to calculate the friction factor,

$$\frac{1}{\sqrt{f}} = -2.0 \ \log\left(\frac{\varepsilon/_D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

The first iteration is started with the value of 0.0208. Several iterations must be made until convergence was achieved. However, the friction factor will varied according to the water velocity since it will affect the Reynolds Number which is one of the components in the friction factor. Therefore, a new calculation will need to be done every time when there is different in velocities. In this study, different velocities will be used ranging from 0.3m/s to 0.8m/s and the friction factor obtained is displayed in Table 7.

Table 7: Friction Factor for Different Velocities in Water Verification

Velocity, m/s	Friction Factor, f
0.3	0.02239
0.4	0.02159
0.5	0.02106
0.6	0.02069
0.7	0.02040
0.8	0.02018

A fully developed flow is required in this study. To determine the entrance region, the equation below is used as all the simulation will be turbulent:

For 0.30m/s,

$$l_e = 4.4 \times D \times Re^{\frac{1}{6}} = 4.4 \times 0.2 \times 66463^{\frac{1}{6}} = 5.60m$$

For 0.80m/s,

$$l_e = 4.4 \times D \times Re^{\frac{1}{6}} = 4.4 \times 0.2 \times 177235^{\frac{1}{6}} = 6.60m$$

By adding with 10 meters of fully turbulent region, it will be safer to simulate the data with a pipe length of 20 meters. This will ensure the flow to be in the fully developed region and therefore more accurate results can be obtained.
After the friction factor is determine, the pressure loss can be calculated using the formula:

Pressure Loss, $\Delta P = f\,\frac{l}{D}\,\frac{\rho V^2}{2} = 0.0224\ \times\ \frac{20}{0.2}\ \times\ \frac{997 \times 0.3^2}{2} = 100.43$ Pa

Pressure Loss Over Length, $\Delta P/\Delta L = \frac{3.894}{20} = 5.02$ Pa/m

Same steps are repeated and the theoretical results were obtained.

<u>Theoretical Result vs Simulated Result</u>

From Table 8, the results shown that the simulated data are reliable since all the percentage errors are very low. The percentage error is calculated by comparing the theoretical result with the simulated result. Besides that, it was also shown that the increase of velocity will cause an increase in the pressure drop.

Table 8: Theoretical Result vs Simulated Result for Water Verification

Velocity, m/s	**Pressure Loss Over Length, Pa/m (Theoretical)**	**Pressure Loss Over Length, Pa/m (Simulated)**	**Percentage Error, %**
0.3	5.021	5.009	0.24
0.4	8.610	8.593	0.20
0.5	13.125	13.099	0.19
0.6	18.562	18.561	0.01
0.7	24.919	24.915	0.02
0.8	32.195	32.186	0.03

The relationship between the theoretical and simulated data is shown in Figure 10.

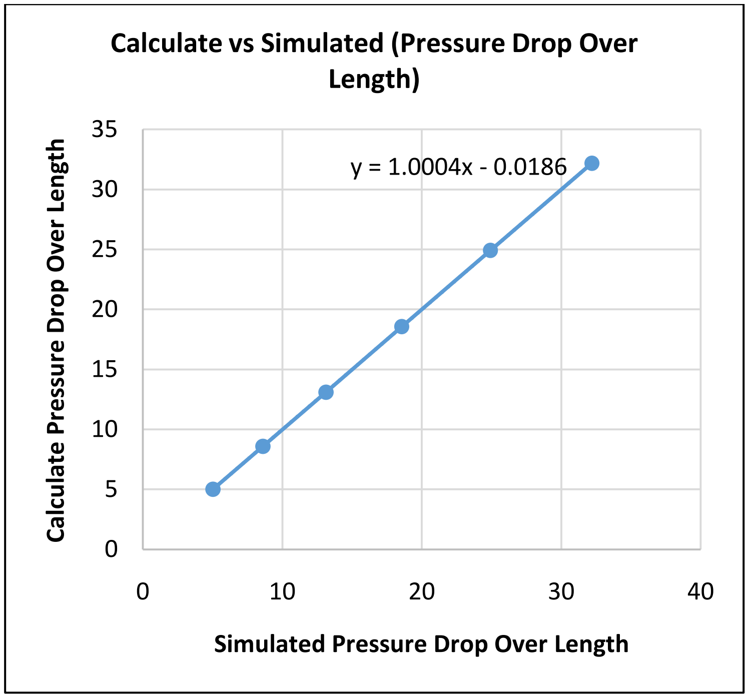

Figure 10: Graph of Simulated Pressure Drop vs Theoretical Pressure Drop for Water Verification

$$\theta = \tan^{-1}(\, 1.0004 \,) = 45.01°$$

From the calculation, it was proved that the line is 45 degrees which indicates that the result is accurate. Therefore, the results for water flow is accepted and verified.

4.2.2 Oil Verification (Diesel 2D)

<u>Theoretical Calculation</u>

Oil Temperature, T = 60°F

Density of Water, ρ = 53 lb/ft^3 or 848.979 kg/m^3

Velocity of Oil, V = 0.5 m/s

Diameter of Pipe, D = 0.2m

Dynamic Viscosity of Oil, μ = 4.1 Centipoise or 4.1 x 10^{-3} Pa.s

Reynolds Number, Re = $\frac{\rho VD}{\mu} = \frac{848.979 \times 0.5 \times 0.2}{4.1 \times 10^{-3}} = 2.07\ x\ 10^4$ (turbulent)

Sand Grain Roughness, ε = 0.15mm

Using Colebrook Equation to calculate the friction factor,

$$\frac{1}{\sqrt{f}} = -2.0\ \log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

Table 9: Friction Factor for Different Velocities in Oil Verification

Velocity, m/s	Friction Factor, f
0.5	0.02726
1.0	0.02402
1.5	0.02259
2.0	0.02176
2.5	0.02121
3.0	0.02082

Next, the pressure loss can be calculated using the formula:

Pressure Loss, ΔP = $f\frac{l}{D}\frac{\rho V^2}{2} = 0.02726 \times \frac{20}{0.2} \times \frac{848.979 \times 0.5^2}{2}$ = 289.3 Pa

Pressure Loss Over Length, ΔP/ΔL = $\frac{289.3}{20}$ = 14.465 Pa/m

Same steps are repeated and the theoretical results were obtained.

Theoretical Result vs Simulated Result

From Table 10, the percentage errors between the theoretical and simulated data are quite low. Therefore, the results are accurate and acceptable. The relationship between the theoretical and simulated data is shown in Figure 11.

Table 10: Theoretical Result vs Simulated Result for Oil Verification

Velocity, m/s	**Pressure Loss Over Length, Pa/m (Theoretical)**	**Pressure Loss Over Length, Pa/m (Simulated)**	**Percentage Error, %**
0.5	14.465	13.895	3.94
1.0	50.974	49.814	2.28
1.5	107.891	107.770	0.11
2.0	184.773	184.644	0.07
2.5	281.423	281.215	0.07
3.0	397.736	398.134	0.10

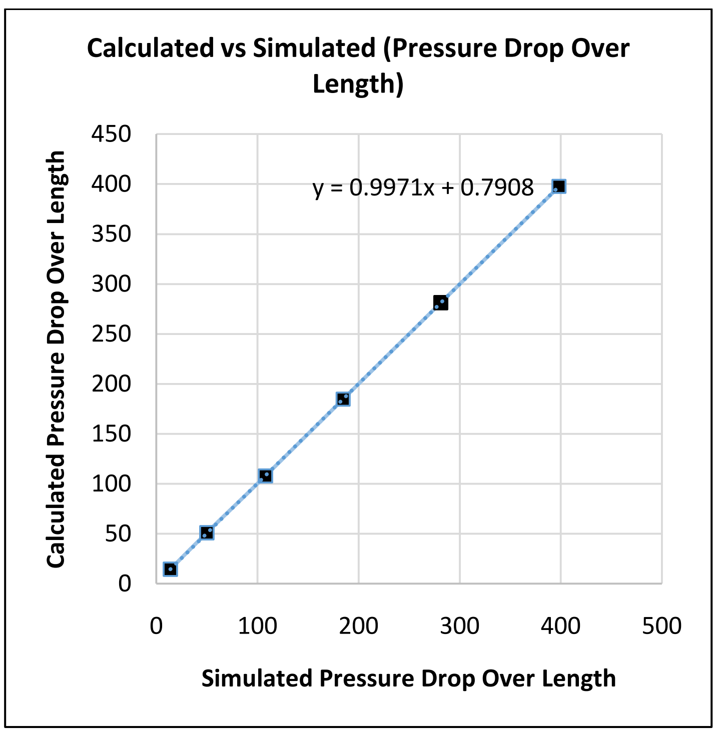

Figure 11: Graph of Simulated Pressure Drop vs Theoretical Pressure Drop for Oil Verification.

From Figure 11,

$$\theta = \tan^{-1}(\, 0.9971 \,) = 44.92°$$

The calculation showed that the line is 44.92 degrees which is almost 45 degrees. This indicates that the result is accurate and reliable. Therefore, the results for oil flow is accepted and verified.

4.3 Oil-Sand Homogeneous Flow

In this simulation, different concentrations of solid particles with different solid particle sizes are added into the oil flow. The solid particle concentrations varied from 10% to 20% whereas the solid particle size varied from 0.25mm to 1.00mm. The simulations are carried out and results are shown below:

Sand concentration, C_v = 10%

Table 11: Homogeneous Flow Simulation Result (Cv=10% & D=0.25mm)

Sand Concentration = 10%						
Sand Particle Diameter = 0.25mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	15.929	389.75	19.49	9218.92	0.0307	34.72
1.0	31.858	1404.00	70.20	18437.84	0.0277	37.72
1.5	47.787	3003.75	150.19	27656.76	0.0263	39.20
2.0	63.717	5204.25	260.21	36875.68	0.0257	40.83

Table 12: Homogeneous Flow Simulation Result (Cv=10% & D=0.50mm)

Sand Concentration = 10%						
Sand Particle Diameter = 0.50mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	15.929	389.75	19.49	9218.92	0.0307	34.72
1.0	31.858	1404.00	70.20	18437.84	0.0277	37.72
1.5	47.787	3003.50	150.18	27656.76	0.0263	39.19
2.0	63.717	5204.25	260.21	36875.68	0.0257	40.83

Table 13: Homogeneous Flow Simulation Result (Cv=10% & D=1.00mm)

Sand Concentration = 10%						
Sand Particle Diameter = 1.00mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	15.929	389.75	19.49	9218.92	0.0307	34.72
1.0	31.858	1404.00	70.20	18437.84	0.0277	37.72
1.5	47.787	3003.75	150.19	27656.76	0.0263	39.20
2.0	63.717	5204.25	260.21	36875.68	0.0257	40.83

From Figure 12 and 13, it was shown that with the increase of mass flow rate, the pressure drop increases from 389.75 Pa to 5204.25 Pa. In this study, the mass flow rate is affected by the fluid velocity and the concentration of sand particle. However, there is a drop in the friction factor from 0.030 to 0.0257. By comparing the result with single phase flow, there is a huge increase in the pressure drop due to the presence of the 10% concentration of sand particle. However, the sand particle diameter did not affect much on the pressure drop.

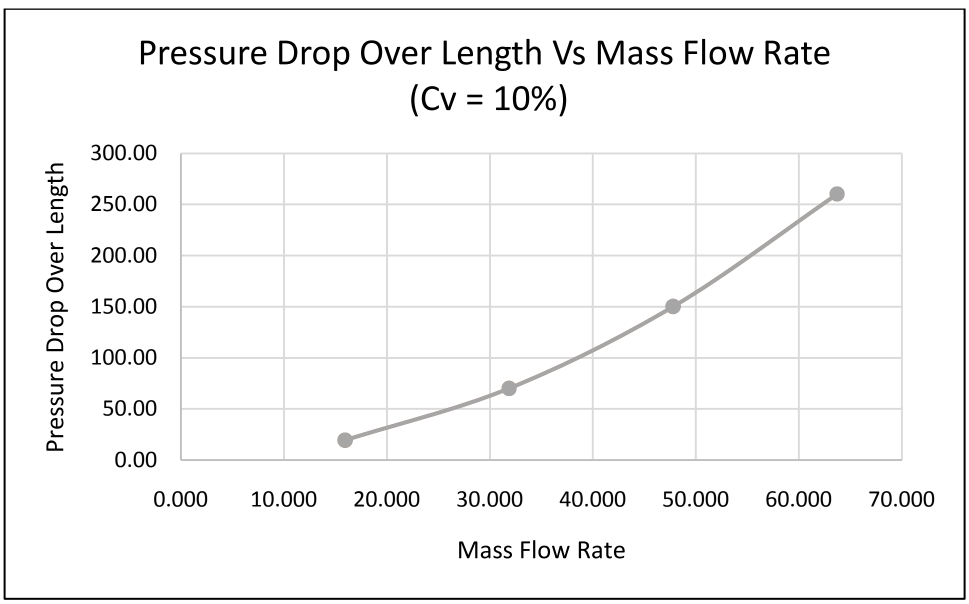

Figure 12: Graph of Pressure Drop Over Length Against Mass Flow Rate for Homogeneous Flow (Cv=10%)

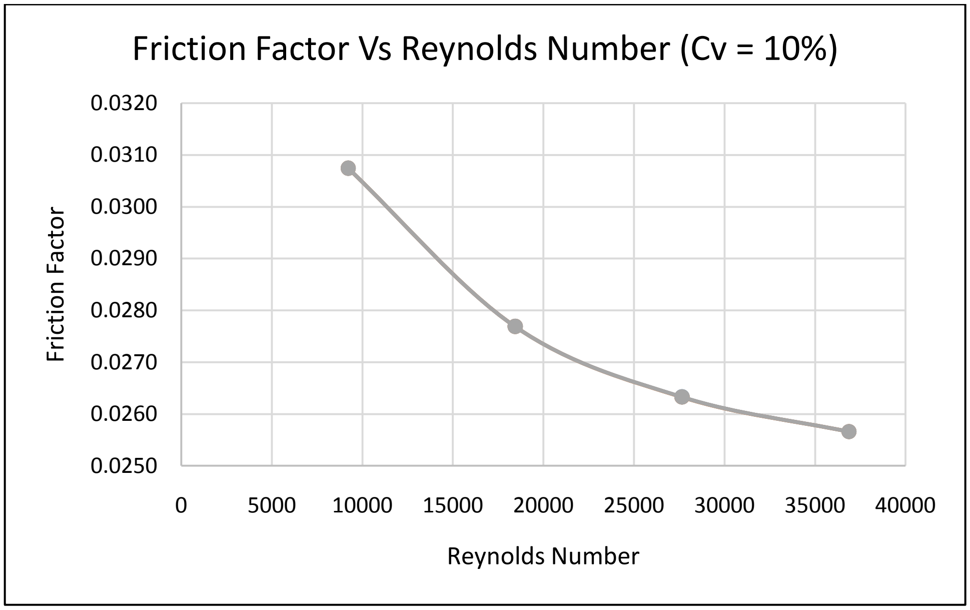

Figure 13: Graph of Friction Factor vs Reynolds Number for Homogeneous Flow (Cv=10%)

<u>Sand concentration, C_v = 15%</u>

Table 14: Homogeneous Flow Simulation Result (Cv=15% & D=0.25mm)

Sand Concentration = 15%						
Sand Particle Diameter = 0.25mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	17.226	451.50	22.58	9969.38	0.0329	56.07
1.0	34.452	1625.25	81.26	19938.77	0.0296	59.42
1.5	51.678	3482.00	174.10	29908.15	0.0282	61.37
2.0	68.903	6037.25	301.86	39877.53	0.0275	63.37

Table 15: Homogeneous Flow Simulation Result (Cv=15% & D=0.50mm)

Sand Concentration = 15%						
Sand Particle Diameter = 0.50mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	17.226	451.25	22.56	9969.38	0.0329	55.98
1.0	34.452	1625.25	81.26	19938.77	0.0296	59.42
1.5	51.678	3482.00	174.10	29908.15	0.0282	61.37
2.0	68.903	6037.25	301.86	39877.53	0.0275	63.37

Table 16: Homogeneous Flow Simulation Result (Cv=15% & D=1.00mm)

Sand Concentration = 15%						
Sand Particle Diameter = 1.00mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	17.226	451.25	22.56	9969.38	0.0329	55.98
1.0	34.452	1625.75	81.29	19938.77	0.0296	59.47
1.5	51.678	3482.00	174.10	29908.15	0.0282	61.37
2.0	68.903	6037.25	301.86	39877.53	0.0275	63.37

From Figure 14 and 15, it was shown that the pressure drop increases from 9969.38 Pa to 39877.53 Pa. However, there is a drop in the friction factor from 0.0329 to 0.0272. By comparing the result with sand concentration of 10%, the pressure drop in 15% of sand concentration is slightly higher and the friction factor is slightly higher too. In addition, the sand particle diameter did not affect much on the pressure drop in this case.

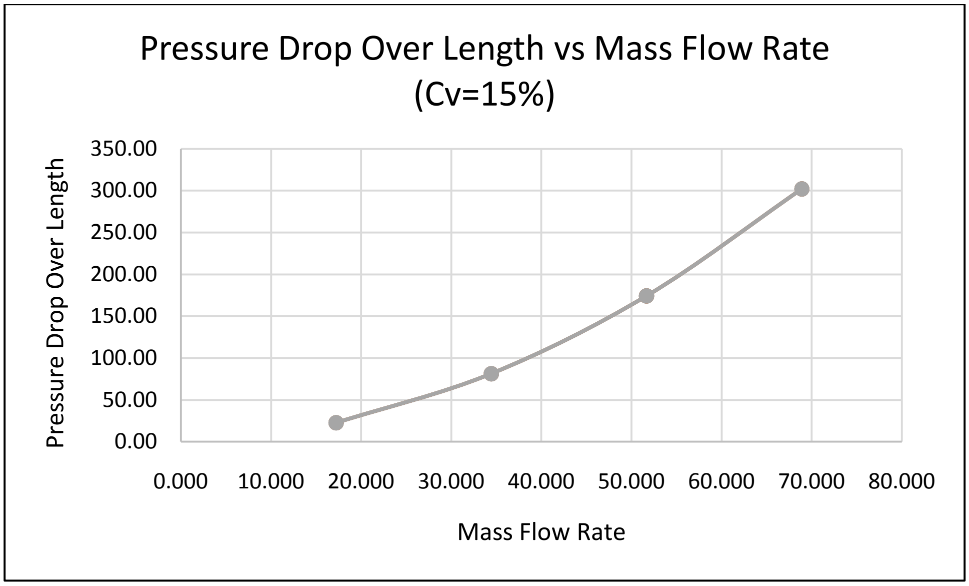

Figure 14: Graph of Pressure Drop Over Length Against Mass Flow Rate for Homogeneous Flow (Cv=15%)

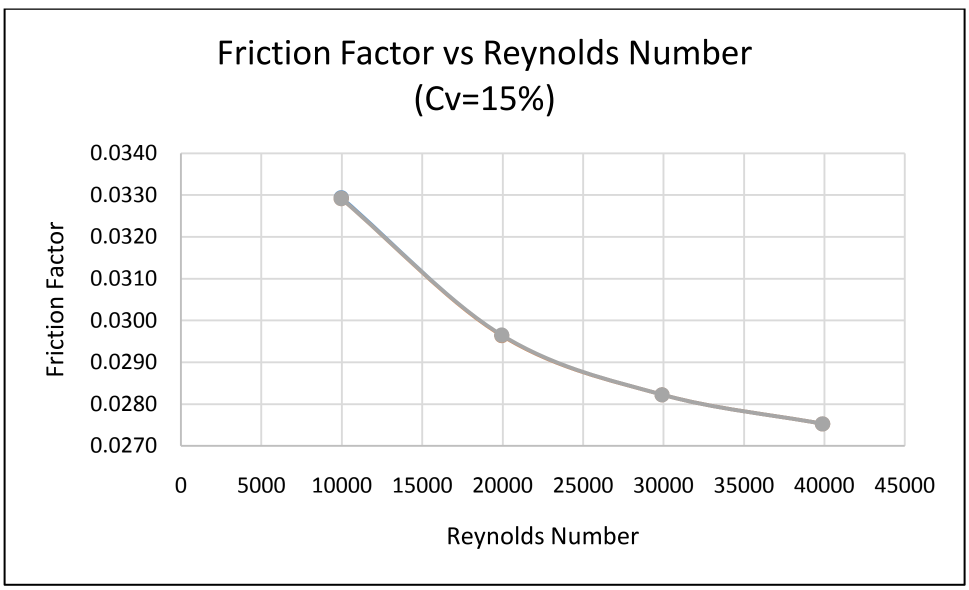

Figure 15: Graph of Friction Factor vs Reynolds Number for Homogeneous Flow (Cv=15%)

Sand concentration, C_v = 20%

Table 17: Homogeneous Flow Simulation Result (Cv=20% & D=0.25mm)

Sand Concentration = 20%						
Sand Particle Diameter = 0.25mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	18.523	515.75	25.79	10719.85	0.0350	78.28
1.0	37.045	1861.75	93.09	21439.69	0.0316	82.62
1.5	55.568	4017.50	200.88	32159.54	0.0303	86.18
2.0	74.090	6929.00	346.45	42879.39	0.0294	87.50

Table 18: Homogeneous Flow Simulation Result (Cv=20% & D=0.50mm)

Sand Concentration = 20%						
Sand Particle Diameter = 0.50mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	18.523	515.75	25.79	10719.85	0.0350	78.28
1.0	37.045	1861.75	93.09	21439.69	0.0316	82.62
1.5	55.568	4017.50	200.88	32159.54	0.0303	86.18
2.0	74.090	6929.00	346.45	42879.39	0.0294	87.50

Table 19: Homogeneous Flow Simulation Result (Cv=20% & D=1.00mm)

Sand Concentration = 20%						
Sand Particle Diameter = 1.00mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	18.523	515.75	25.79	10719.85	0.0350	78.28
1.0	37.045	1861.75	93.09	21439.69	0.0316	82.62
1.5	55.568	4017.50	200.88	32159.54	0.0303	86.18
2.0	74.090	6929.00	346.45	42879.39	0.0294	87.50

From Figure 16 and 17, the pressure drop increases from 10719.85 Pa to 42879.39 Pa with the increase of mass flow rate whereas the friction factor drops from 0.0350 to 0.0294. By comparing the result with the case of sand concentration 15%, the pressure drop increased slightly and the friction factor also increased slightly too. When comparing the pressure drop with single phase flow, there is an increment of almost 80% in the pressure drop.

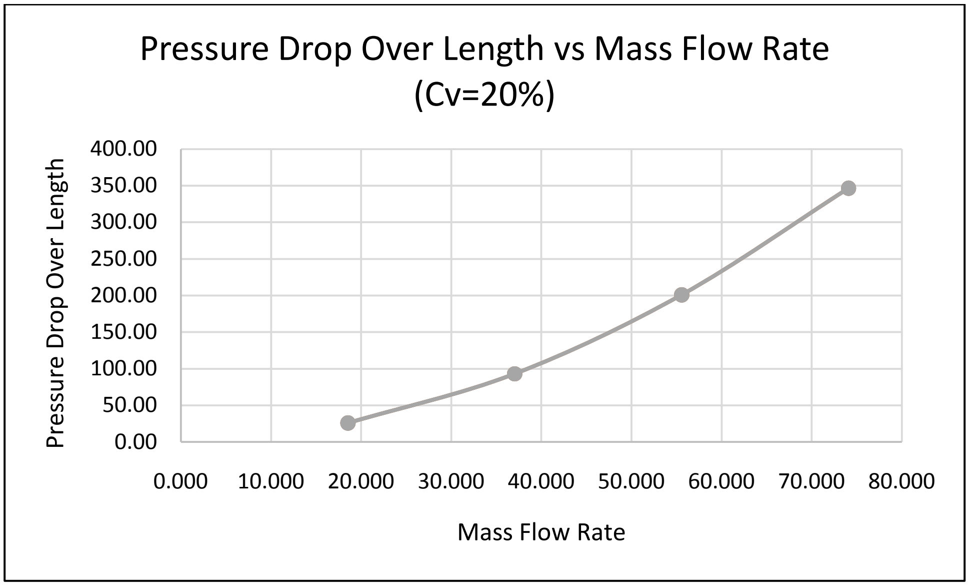

Figure 16: Graph of Pressure Drop Over Length Against Mass Flow Rate for Homogeneous Flow (Cv = 20%)

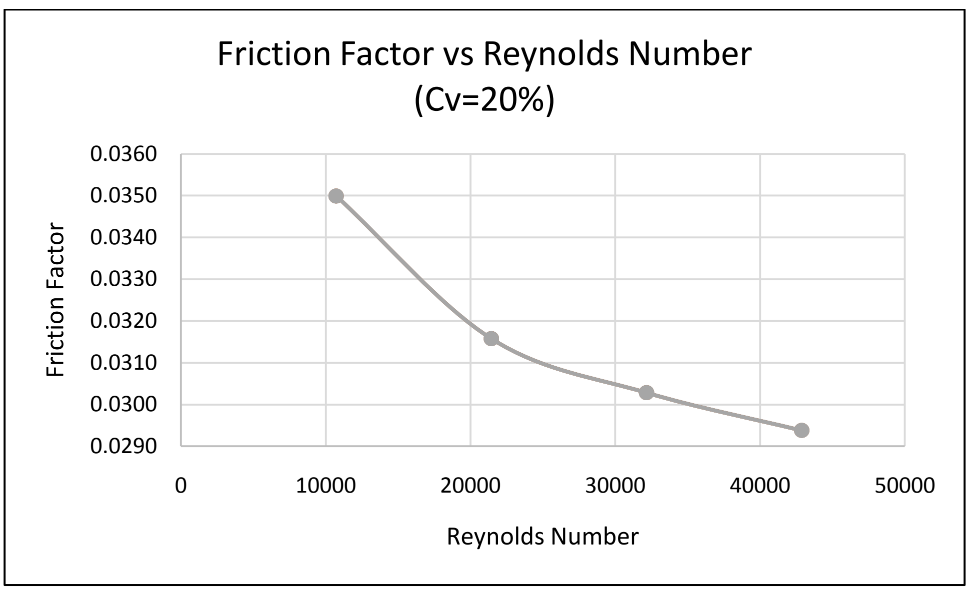

Figure 17: Graph of Friction Factor vs Reynolds Number for Homogeneous Flow (Cv = 20%)

By plotting all the data in Figure 18 and Figure 19, it is showed that the concentration of sand particles and fluid mass flow rate will cause effect on the pressure drop while the size of sand particles has no significant effect on the flow pressure drop. In this simulation, the mass flow rate is affected by the concentration of the density of the fluid as well as the fluid velocity. Furthermore, the density of the fluid is affected by the concentration of solid particles. From the results, it showed that the fluid velocity will have more effect on the friction factor compared to solid particle's concentration. In terms of pressure drop, the fluid velocity will have higher effects too compared to the sand concentration.

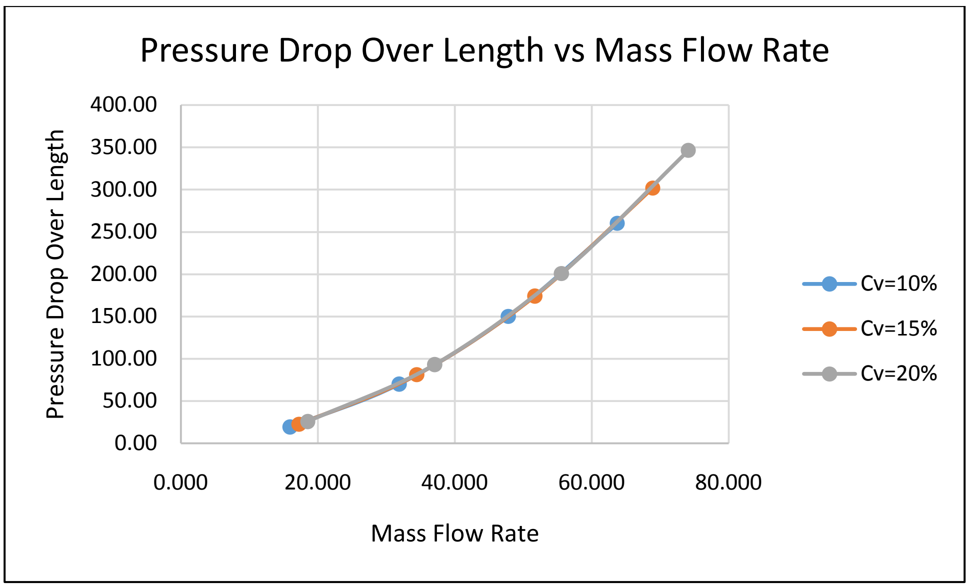

Figure 18: Graph of Overall Pressure Drop Over Length Against Mass Flow Rate for Homogeneous Flow

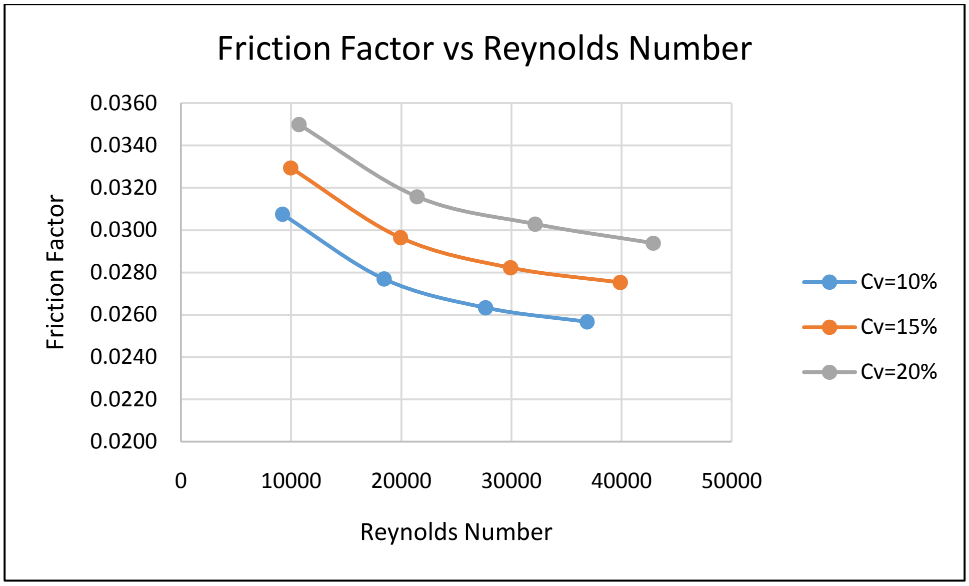

Figure 19: Graph of Overall Friction Factor vs Reynolds Number for Homogeneous Flow

The velocity contour and the pressure contour of the homogeneous two phase flow are shown from Figure 20 to Figure 24.

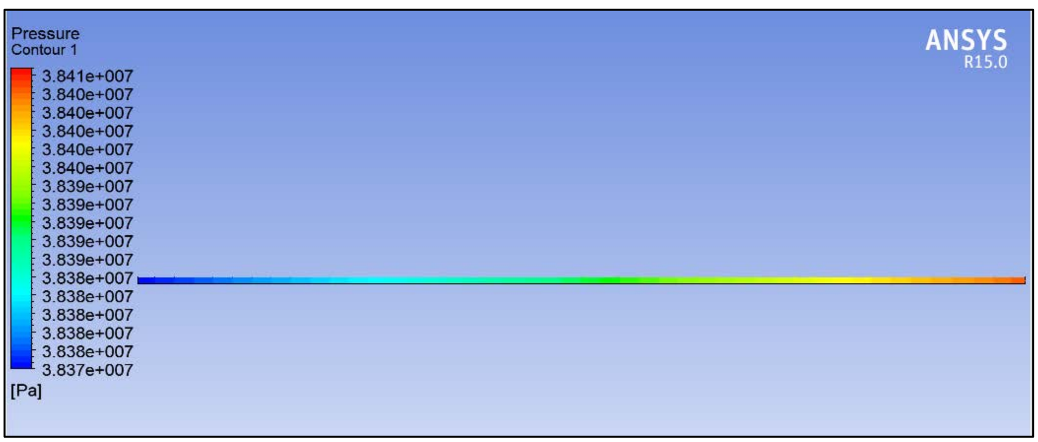

Figure 20: Pressure Contour of Homogeneous Two Phase Flow

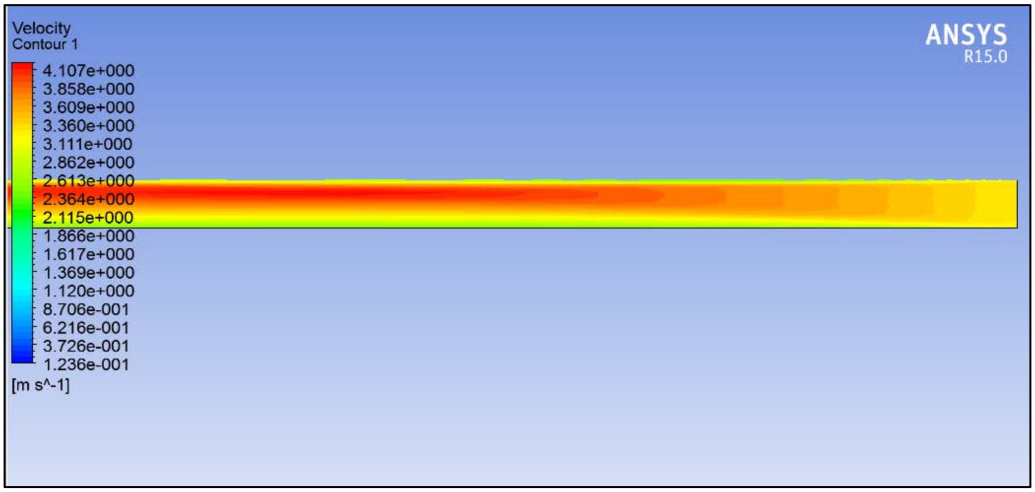

Figure 21: Velocity Contour of Homogeneous Two Phase Flow

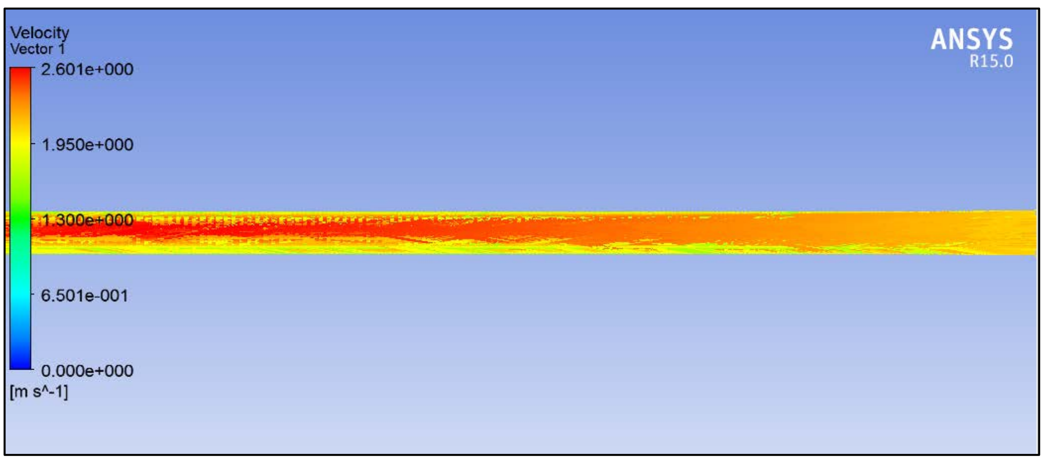

Figure 22: Velocity Vector Contour of Homogeneous Two Phase Flow (Inlet)

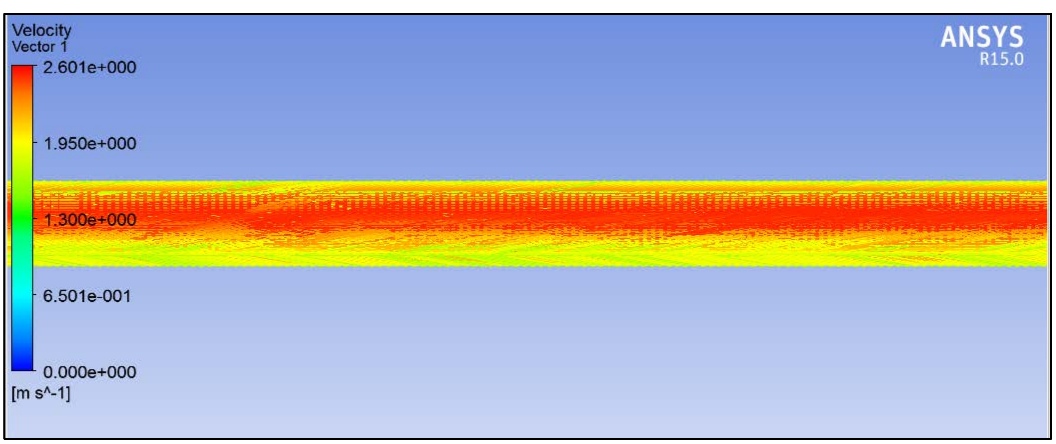

Figure 23: Velocity Vector Contour of Homogeneous Two Phase Flow (Middle)

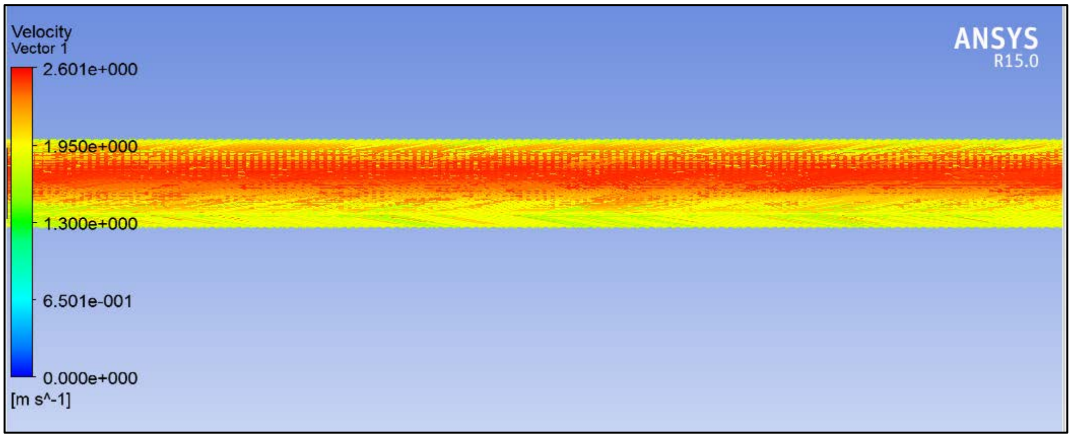

Figure 24: Velocity Vector Contour of Homogeneous Two Phase Flow (Outlet)

4.4 Two-Layer Flow (Homogeneous Flow with Sand Bed)

In the study of two layer flow, there is the presence of the sand bed and also the homogeneous mixture flow. To simplify the simulation, the dead bed part in the flow is cut and high friction is applied on the cut part. The flow is modeled as shown in Figure 25 and Figure 26.

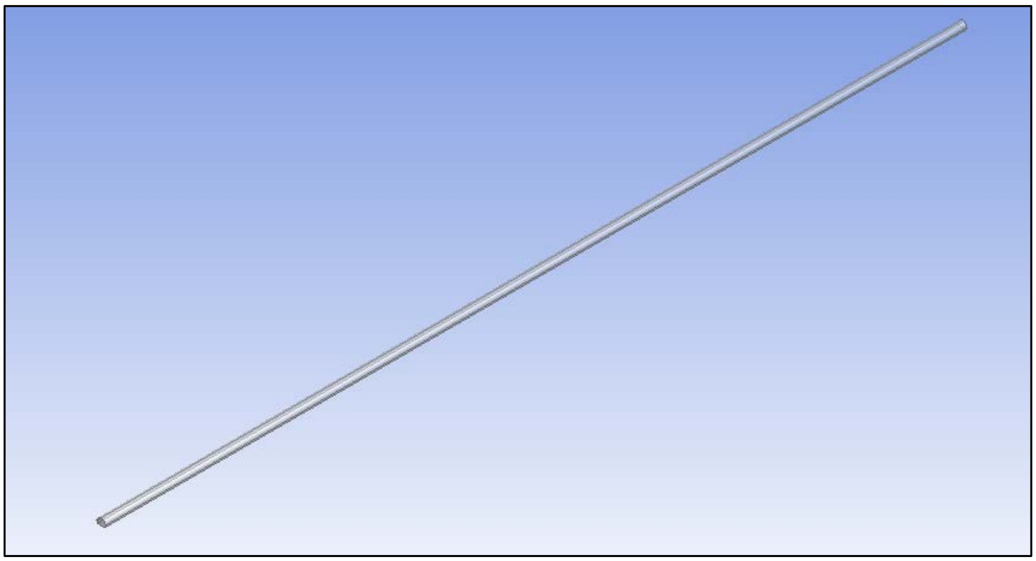

Figure 25: Geometry for two layer two phase flow pipe

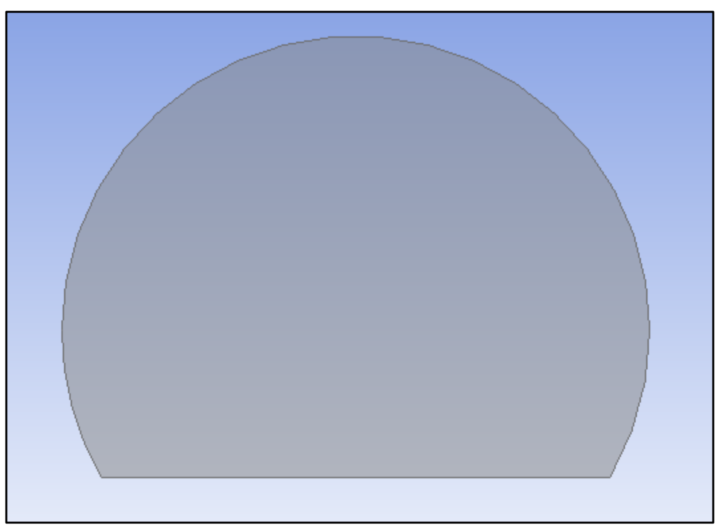

Figure 26: Front view of two layer two phase flow pipe

The pipe is meshed and showed in Figure 27 and Figure 28.

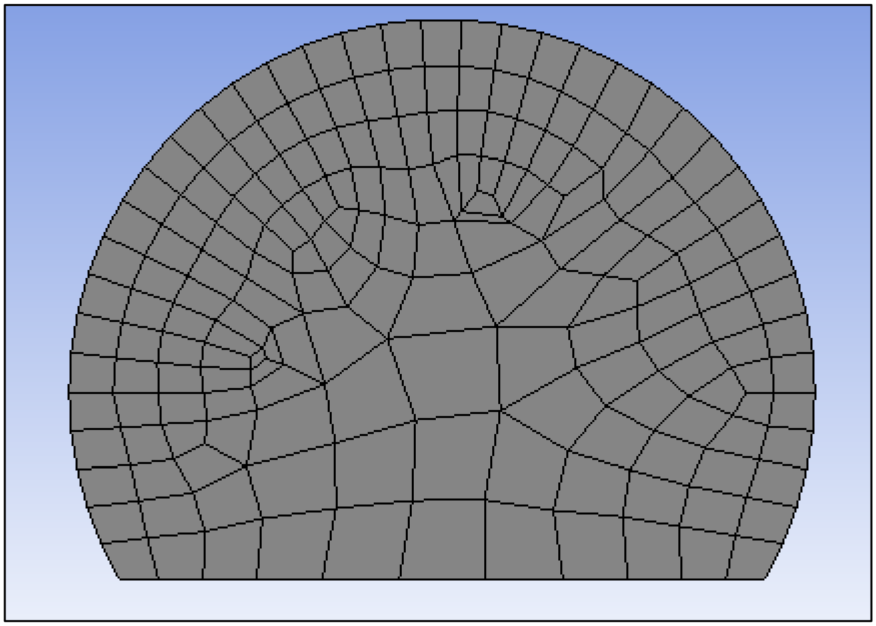

Figure 27: Front mesh of two layer flow pipe

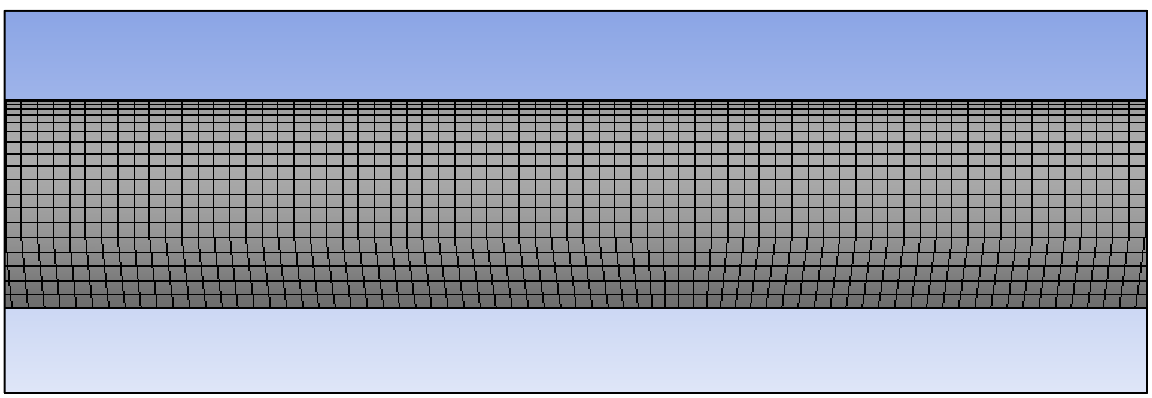

Figure 28: Side view of the mesh for two layer flow pipe

For two layer two phase flow, the simulation will be tested with different fluid velocity, three sand concentrations with fixed sand size which is 0.25mm. The results of the simulation are shown below:

Table 20: Two Layer Two Phase Flow - Cv=10%

Sand Concentration = 10%						
Sand Particle Diameter = 0.25mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	15.011	1448.00	72.40	28040.72	0.1768	400.53
1.0	30.021	5512.00	275.60	56081.45	0.1682	440.67
1.5	45.032	12204.00	610.20	84122.17	0.1655	465.57
2.0	60.042	21472.00	1073.60	112162.89	0.1638	481.04

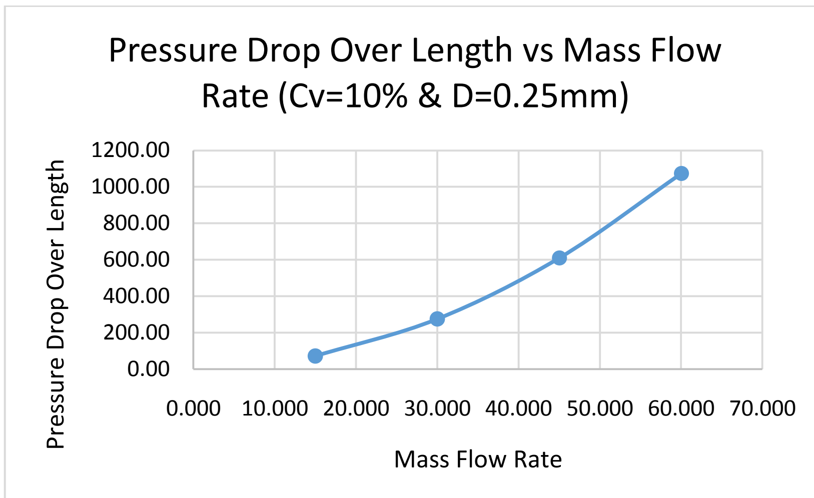

Figure 29: Graph of Pressure Drop Over Length vs Mass flow rate of two layer two phase flow with Cv = 10%

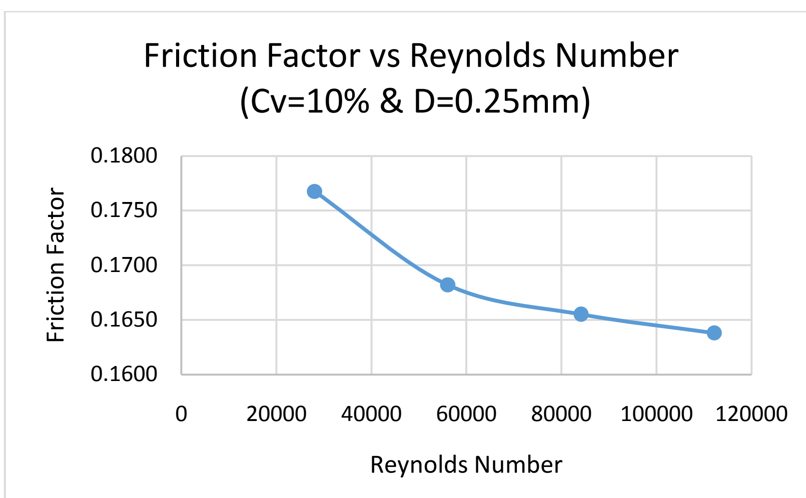

Figure 30: Graph of Friction Factor vs Reynolds Number of two layer two phase flow with Cv = 10%

Table 21: Two Layer Two Phase Flow - Cv=15%

Sand Concentration = 15%						
Sand Particle Diameter = 0.25mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	16.232	1684.00	84.20	25327.89	0.1901	482.10
1.0	32.465	6436.00	321.80	50655.78	0.1816	531.30
1.5	48.697	14224.00	711.20	75983.67	0.1784	559.19
2.0	64.930	25048.00	1252.40	101311.55	0.1767	577.80

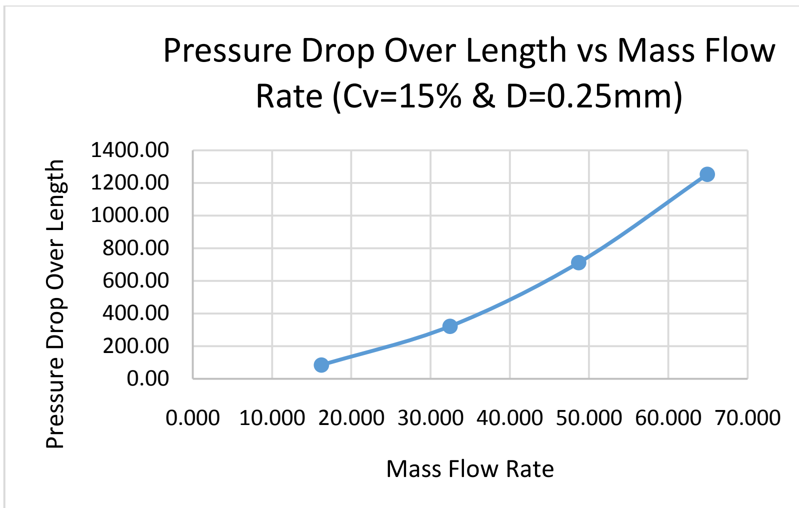

Figure 31: Graph of Pressure Drop Over Length vs Mass flow rate of two layer two phase flow with Cv = 15%

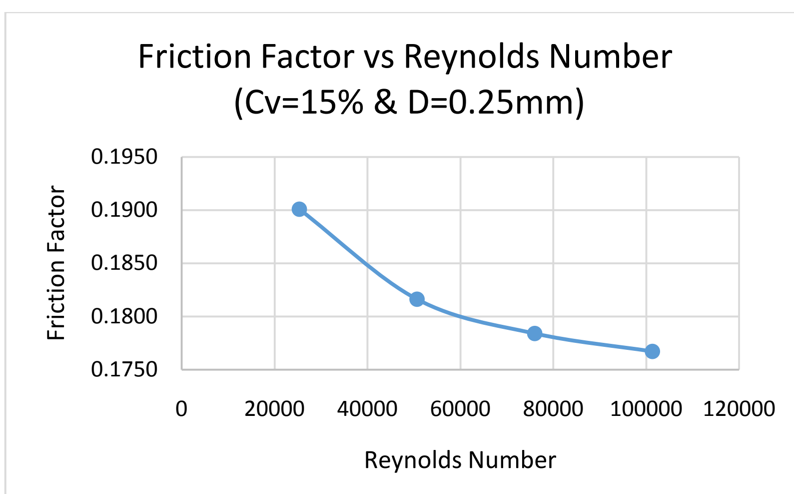

Figure 32: Graph of Friction Factor vs Reynolds Number of two layer two phase flow with Cv = 15%

Table 22: Two Layer Two Phase Flow - Cv=20%

Sand Concentration = 20%						
Sand Particle Diameter = 0.25mm						
Velocity, (m/s)	Mass Flow Rate, (kg/s)	ΔP, (Pa)	ΔP/ΔL, (Pa/m)	Re	f	% diff
0.5	17.454	1940.00	97.00	22504.32	0.2037	570.59
1.0	34.909	7416.00	370.80	45008.65	0.1946	627.43
1.5	52.363	16408.00	820.40	67512.97	0.1914	660.40
2.0	69.818	28888.00	1444.40	90017.29	0.1895	681.72

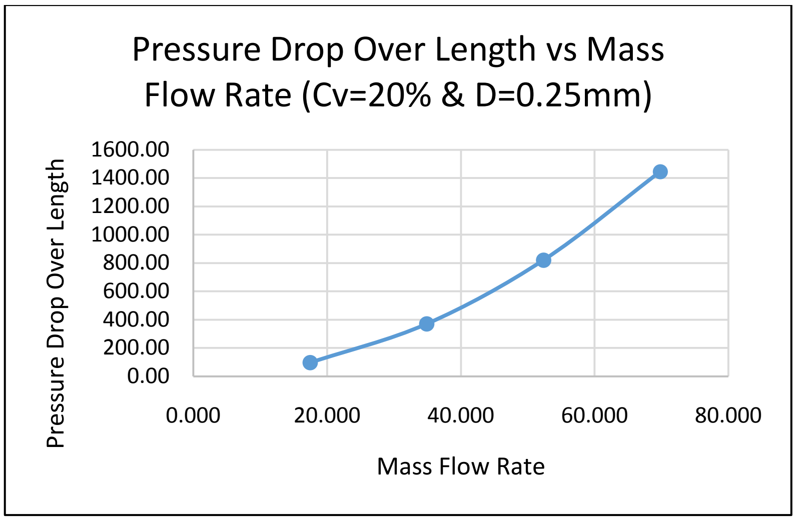

Figure 33: Graph of Pressure Drop Over Length vs Mass flow rate of two layer two phase flow with Cv = 20%

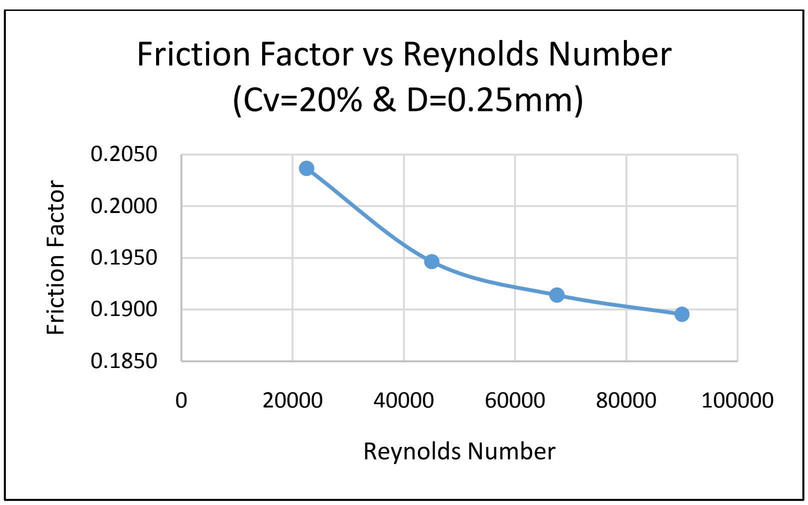

Figure 34: Figure 27: Graph of Friction Factor vs Reynolds Number of two layer two phase flow with Cv = 20%

Data from Table 20 to Table 22 are plotted in one graph as shown in Figure 35 and Figure 36.

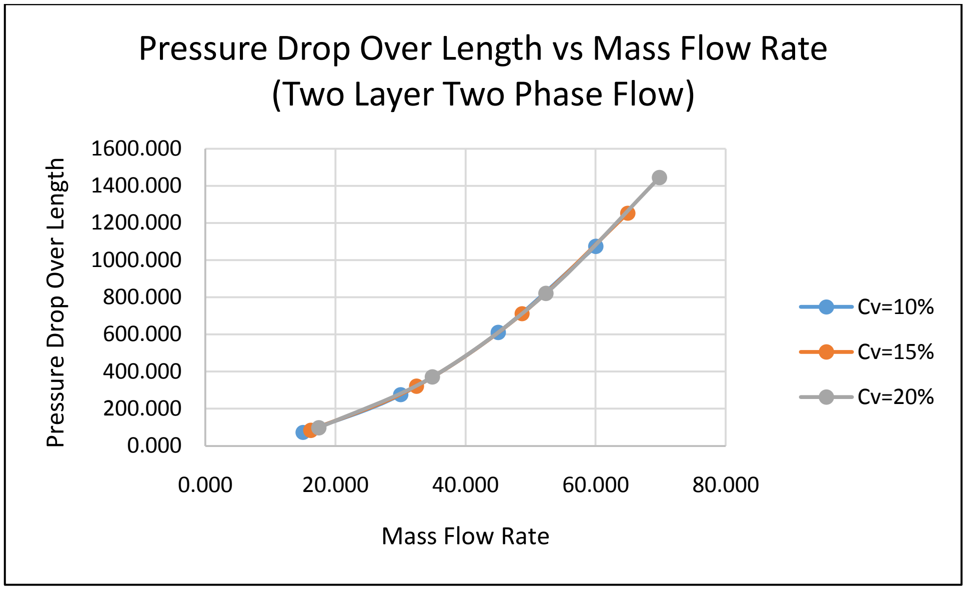

Figure 35: Graph of Pressure Drop Over Length vs Mass Flow Rate for Two Phase Flow

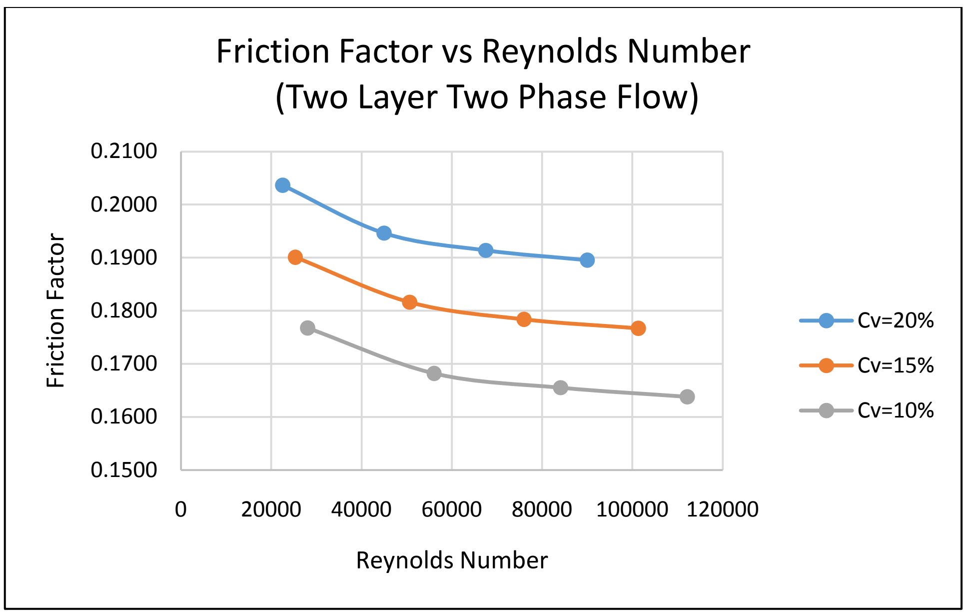

Figure 36: Graph of Friction Factor vs Reynolds Number for Two Phase Flow

From Figure 35 and Figure 36, it can be seen that the increase in mass flow rate will also cause the increase in the pressure drop. The pressure drop increases from 1448 Pa to 28888 Pa as the mass flow rate increases from 15kg/s to 70kg/s. In this study, the mass flow rate is affected by density of the fluid and also its velocity. The density of fluid is determined by the concentration of oil and also sand.

On the other hand, the friction factor of the flow decreases when concentration of the sand increases. The friction factor decreases from 0.2037 to 0.1638 as the Reynolds Number increases from 22500 to 112000. However, the velocity does not affect much on the friction factor as shown in Figure 31. The velocity only causes slight drop in the pressure drop compared to the sand concentration.

The velocity contour and the pressure contour of the two layer two phase flow are shown from Figure 37 to Figure 41.

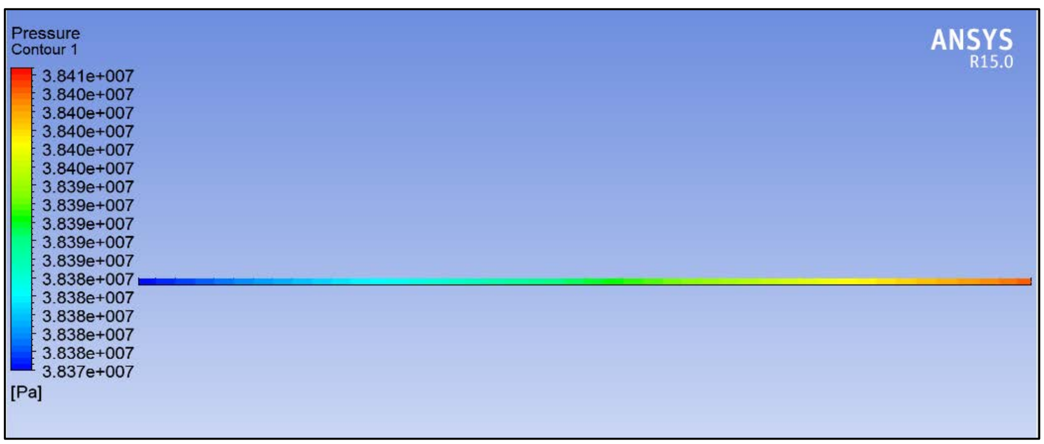

Figure 37: Pressure Contour of Two Layer Two Phase Flow

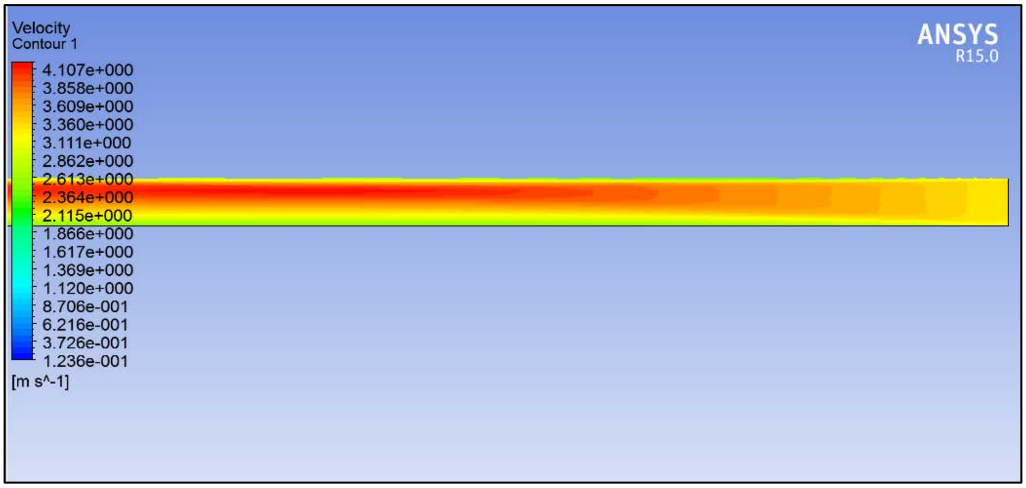

Figure 38: Velocity Contour of Two Layer Two Phase Flow

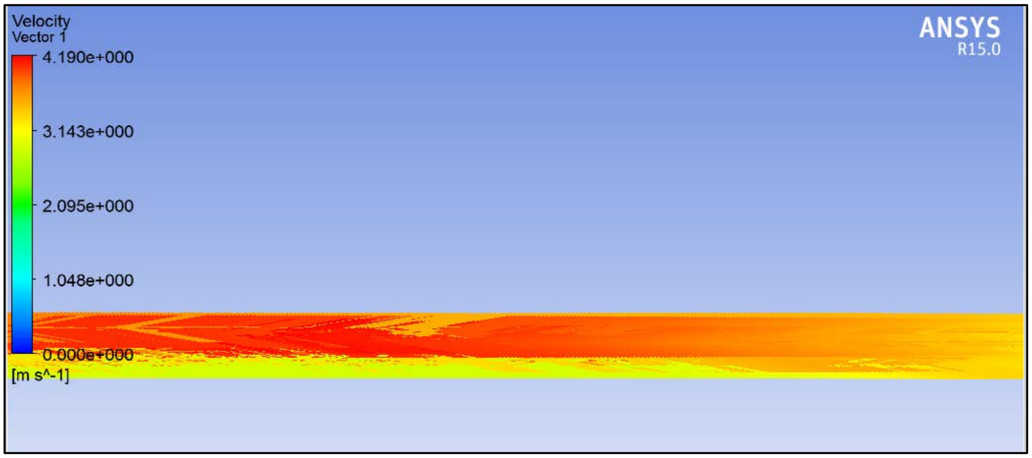

Figure 39: Velocity Vector Contour of Two Layer Two Phase Flow (Inlet)

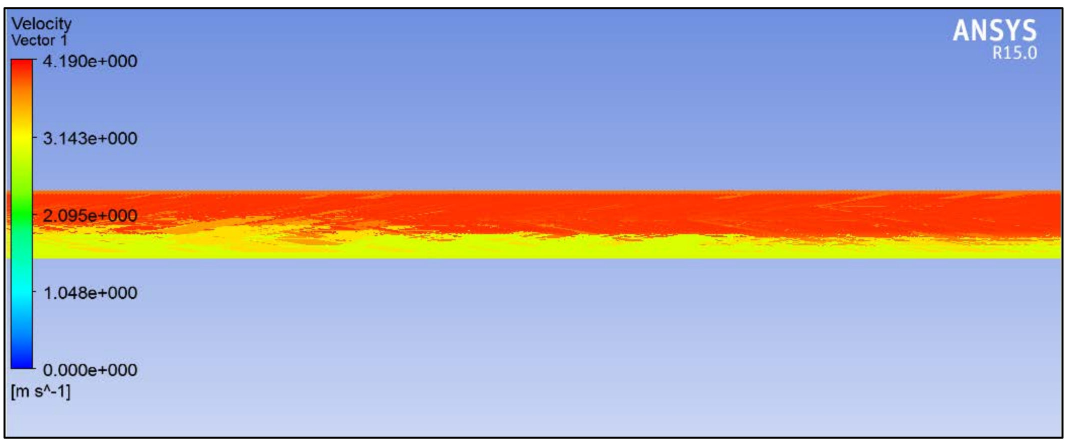

Figure 40: Velocity Vector Contour of Two Layer Two Phase Flow (Middle)

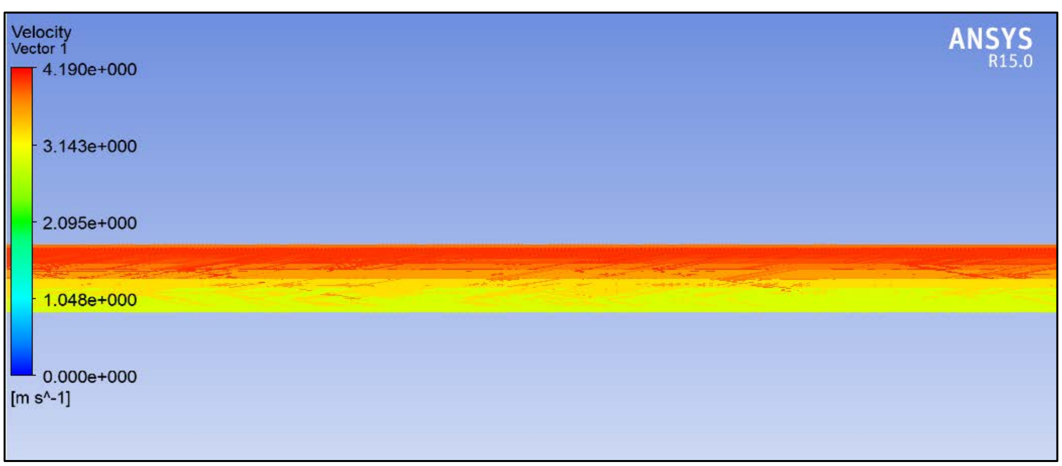

Figure 41: Velocity Vector Contour of Two Layer Two Phase Flow (Outlet)

In conclusion, the increase in sand concentration will cause the increase of flow's friction factor but have slight effect on the flow pressure drop. The increase of fluid velocity will cause huge increase in the flow pressure drop but has less effect on the friction factor.

CHAPTER 5:
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The presence of solid particles in flow will affect the pressure loss in the pipe line and also the friction factor of the flow. In order to ensure the accuracy of results, the single and two phases solid-in-liquid of water and oil are simulated and validated via comparison with the available design equation for friction and pressure losses in pipe flow.

For single phase flow, the results obtained are having percentage errors of less than 5% which indicates that the models are acceptable. When plotted the theoretical result against simulated result, the graph for both cases (water and oil) showed 45 degrees which implicates that the result is accurate.

In homogeneous two phase flow, higher fluid velocities will have higher pressure loss and the increase in sand concentration will also have higher pressure loss. The friction factor increases when the sand concentration increases. However, the friction factor of flow decreases when the velocity increases. The sizes of the sand particles do not have significant effect on the pressure drop.

In two phase flow, the increase in sand concentration will cause the increase of flow's friction factor but have slight effect on the flow pressure drop. The increase of fluid velocity will cause huge increase in the flow pressure drop but has less effect on the friction factor. In conclusion, all the objectives have been achieved.

5.2 Recommendations

There are some recommendations and improvements can be made in this project which are:

- Investigating the effect of pipe diameter and length on the pressure loss.
- An experiment can be set up to compare the actual results with the simulated results.
- Project can be continued with flow with bends and joints.
- The project can be continued with Non-Newtonian fluids.

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